ROBERT OPPENHEIMER

THE TREE OF KNOWLEDGE

In April Dr. Oppenheimer spoke to a group of editors and journalists from all over the world who had gathered in Washington for a meeting of the International Press Institute. He spoke without a prepared text, using only notes; the article which follows is published substantially as it was recorded during the lecture.

WHEN I speak to the press I am aware that I am talking to a group of men who have a singularly critical destiny in these rather peculiar times. Those of us whose work it is to preserve old learning, and to find new, look to the press to keep the channels of truth and communication open and to keep men in some sense united in common knowledge and common humanity.

I want to talk about the nature and structure of our knowledge today and how it has altered and complicated the problems of the press. There are enormous differences between our world of learning today—our Tree of Knowledge—and those of Athens, or the Enlightenment, or the dawn of science in fifteenth- and sixteenth-century Europe. You can get some suggestion of how shattering these changes have been if you remember that Plato, when he tried to think about human salvation and government, recommended mathematics as one of the ways to learn to know the truth, to discriminate good from evil and the wise from the foolish. Plato was not a creative mathematician, but students confirm that he knew the mathematics of his day, and understood it, and derived much from it.

Today, it is not only that our kings do not know mathematics, but our philosophers do not know mathematics and—to go a step further—our mathematicians do not know mathematics. Each of them knows a branch of the subject and they listen to each other with a fraternal and honest respect; and here and there you find a knitting together of the different fields of mathematical specialization. In fact, a great deal of progress in mathematics is a kind of over-arching generalization which brings things that had been separate into some kind of relation. Nevertheless, it is not likely today that our most learned advisers—the men who write in the press and tell us what we may think—would suggest that the next President of the United States be able to understand the mathematics of the day.

YIELDING BOUNDARIES

THE first characteristic of scientific knowledge today—a trivial and pedestrian characteristic—is that its growth can be measured. When I talk of "science" here I would like to use the word in the broadest sense to include all man's knowledge of his history and behavior, his knowledge, in fact, of anything that can be talked of in an objective way so that people all over the world can understand it, know what the scientist has done, reproduce it, and find out if it is true or not. It is hard to measure the growth of science defined in these terms in a sensible way but it can be measured in fairly foolish ways.

One way of measuring science, for example, is to find out how many people are engaged in it. I know a young historian of science who has amused himself by counting the scientists of the last two centuries and he has found that their number has, quite accurately, doubled about every ten years. Professor Purcell of Harvard put the same conclusion another way the other day when he said, "Ninety per cent of all scientists are alive." This gives some notion of the changes involved.

I must, however, qualify this trend in two ways. First, it cannot continue, because if it went on for another century, then everyone would be a scientist—there would be nobody else left. So a kind of saturation is setting in and the rate of science's growth is slowing down. The second qualification is that what might be called the "stature" of science is not proportional to its volume; it may be proportional to the cube root of its volume or something like that. In short, every scientist is not a Newton and the proportion of Newtons among all scientists tends to decline as the number of people involved gets bigger.

Despite all qualification, though, the fact remains that the growth in the number of people in science and the growth in firm knowledge—important, non-trivial knowledge of the kind that appears in learned journals and books—have been more or less parallel; and this growth will continue, although the increase in it is bound to taper off. The result is that nearly everything that is now known was not in any book when most of us went to school; we cannot know it unless we have picked it up since. This in itself presents a problem of communication that is nightmarishly formidable.

On the other hand, there is a more encouraging aspect of this scientific knowledge. As it grows, things, in some ways, get much simpler. They do not get simpler because one discovers a few fundamental principles which the man in the street can understand and from which he can derive everything else. But we do find an enormous amount of order. The world is not random and whatever order it has seems in large part "fit," as Thomas Jefferson said, for the human intelligence. The enormous variety of facts yields to some kind of arrangement, simplicity, generalization.

One great change in this direction—and it has not yet, I think, fully come to public understanding—is that we are beginning to see that the hard boundaries which once seemed to separate the parts of the natural world from each other are now yielding to some kind of inquiry. We are beginning to see ways across the gaps between the living and the dead, the physical and the mental.

Let me give just a few illustrations:

- It is probably not an accident, although it is not really understood, that the age of the earth—some six or seven billion years according to calculation by radioactive techniques—is very close to the period required for the most distant nebulae to recede into the furthest reaches of space. We can picturesquely define that time by saying that during it things were a lot closer together than they are now and the state of the material universe was very different. Some years ago the brilliant Russian biochemist Oparin suggested that when the atmosphere had no oxygen in it, certain conditions could have prevailed on earth under which life could have originated from inorganic matter. There has since been confirmation in Urey's laboratory and this hypothesis turns out to be true. Although mermaids and heroes do not walk out of the test tube, we do see that quite reasonable accounts of the origin of life are not too far from our grasp.

- The recent research on how the genetic mechanisms of all living material operate shows how certain proteins have special information-bearing properties—how they can store information and transmit it from one generation to another.*

- The study of how the nerve impulses from our sense organs to the brain can be modulated and altered by the perceptive apparatus of the animal—often it is an animal rather than a man—give us some notion both of the unreliability of our sense impressions and of the subtlety of the relations between thought and the object of thought.

All these problems, which even in the nineteenth century seemed to obstruct the possibility of a unified view of the great arch of nature, are yielding to discovery; and in all science there is a pervasive, haunting sense that no part of nature is really irrelevant to any other.

GAY AND WONDERFUL MYSTERY

BUT the model of science which results from all this investigation is entirely different from a model which would have seemed natural and understandable to the Greeks or the Newtonians. Although we do start from common human experience, as they did, we so refine what we think, we so change the meaning of words, we build up so distinctive a tradition, that scientific knowledge today is not an enrichment of the general culture. It is, on the contrary, the possession of countless, highly specialized communities who love it, would like to share it, would very much like to explain it, and who make some efforts to communicate it; but it is not part of the common human understanding. This is the very strange predicament to which the press addresses itself today and to which it can give, I believe, only a partial solution.

It would of course be splendid—and one often hears this—if we could say that while we cannot know the little details about the workings of atoms and proteins and the human psyche, we *can* know the fundamental principles of science. But I am afraid that this is only marginally

*An account of this development, by F.H.C. Crick, appeared in *Scientific American*, September 1957.

true. The fundamentals of physics are defined in terms of words that refer to an experience that lay people have not had and that very few people have run across in their education.

For example, in my opinion, it is almost impossible to explain what the fundamental principle of relativity is about, and this is even more true of the quantum theory. It is only possible to use analogies, to evoke some sense of understanding. And as for the recent discovery—the very gay and wonderful discovery for which Dr. Yang and Dr. Lee were awarded the Nobel Prize—that nature has a preference for right-handed or left-handed screws in certain situations and is not indifferent to the handedness of the screw—to explain this is, I believe, quite beyond my capacity. And I have never heard anyone do it in a way that could be called an enrichment of culture.

To sum up the characteristics of scientific knowledge today, then, I would say that it is mostly new; it has not been digested; it is not part of man's common knowledge; it has become the property of specialized communities who may on occasion help one another but who, by and large, pursue their own way with growing intensity further and further from their roots in ordinary life.

We must always remember that, like most human accomplishments, the sciences have grown out of a long, accumulating experience of error, astonishment, invention, and understanding. Taken as a whole, they constitute a series of traditions; and these traditions—once largely common, now largely separate—are as essential to understanding a part of biology or astronomy or physics as the general human tradition is to the existence of civilized life. I know that a complete immersion in these many different, related, yet specific traditions is beyond the reach of any one person—that as things stand today, most of us are without any experience, really, in any. We have much in common from the simple ways in which we have learned to live and talk and work together. Out of this have grown the specialized disciplines like the fingers of the hand, united in origin but no longer in contact.

PRACTICAL BOOBY TRAPS

NOW I am going to make a distinction which may seem arbitrarily sharp but which is I think important both to the learned community and the press. I have been talking until now about science as the things we have discovered about nature—incredible things and beautiful and astonishing, but defined, usually, not by any use to which they are put, but simply in terms of the ways in which they were found out. Pure science is thus inherently circumscribed but immensely revealing, showing as it does that left to itself, man's imagination was not a patch on reality.

Seeking out this knowledge is one problem and I am not through with it. But the other problem is that, of course, this knowledge has practical consequences. On it is built the world we live in and the face of that world has been changed, probably more than in any other period of history, by the scientific revolution. Now these practical consequences, because they are intended in some way to be responsive to man's needs, can be talked about in an intelligible way. It is not necessary to know how a nucleus is put together, or what are the laws which determine its behavior, in order to explain what nuclear energy is all about. It may be very hard to explain it well because it involves human choices, options, decisions, prejudices. But I believe that it is no more difficult to write about nuclear energy than about where people go for a holiday. It is not much harder to write about nuclear weapons, except that, to the problems of human variety, there is added the problem of a very great deal of secrecy.

To take another example, it has not been hard to write about the use of vaccines in the prevention of disease and these can be described without elaborate theory. As a matter of fact the vaccines were discovered without much theoretical background and the atomic bomb was made before we had much idea what held nuclei together; we do not have very much idea today.

The press has done an admirable job in explaining these and other practical applications of science—I think it is aware that it has to do a much, much greater one. But there are, I think, some booby traps which stand in its way. I would like to list three of them.

One of the simplest traps is that when technical people talk they always emphasize the fact that they are not sure. Sometimes, as in the case of knowing all the effects of radiation on life, we are not, in fact, sure, because experience takes so long to acquire. But usually the statement that we are not sure is more like the polite comment, "I don't want to bore you but . . ." Statements about scientific matters are not entirely sure—nothing is—but compared to politics they are so extremely sure as to be of a different order of certainty. If a scientist says he is not sure, pay attention to the limits within which he says this—the margin for error he insists on allowing. This margin will not be so wide. Within what limits we are uncertain about the genetic damages of radiation, for example, is not something to worry or wonder about. We know something of the effects on the genes. The differences of opinion over this question lie in quite a different field. They lie in conflicting assessments of the relative gravity of these damages and of other vaster dangers of total nuclear war.

A second trap to beware of is the strange fact that the words scientists use have taken on special meaning so that there is a confusing quality of punning when they discuss technical things and describe their aims. "Relativity" sounds like something that occurs in daily life; it is not. Scientists talk about the "adventure" of science and they are right; but of course in the public mind this is very likely to be identified with looking to see if the other side of the moon is really there. Here the public is wrong. The adventures of science are intellectual adventures, involving discoveries of the inadequacy of our means of describing nature, because it is so unfamiliar and strange. Space travel has, no doubt, its value and virtue, but it is in no way related to the great adventures of science. It would be, of course, if we could go out two or three billion light-years and see what is going on there, because it is hard to see that far with telescopes. But this is not the same thing as the progress of human learning and understanding.

A third trap and a serious one—it has infested the discussion of radioactive fallout—is that in most technical explanations, very large numbers occur, and it is often hard to convey their implications sensitively. It may be equally true to say, for instance, that something will cause 10,000 casualties and that these casualties will affect a hundred-thousandth of the population of the world; but one statement can make the effect seem rather small and the other can make it very big. We cannot get over the habit of talking in numbers but it takes some exposition if we are to avoid creating the wrong impression.

I have one example of this. It has to do with radioactive fallout. I know nothing about the main efforts being made to eliminate fallout at present but it is obvious that they have to do with the elimination of fissionable material from bombs. The first step is to take the casing away from big bombs and the next step, presumably, is to take away much—or even all—of the rest.

"What's so terrible? It's a deadly rock but it's a clean *rock."*

I have some understanding of this as a technical problem and some idea of the benefits which will accrue from it. But in an old day, when we had the first primitive, tiny, atomic weapons, there was also a contrast. The story is in the public domain and I am surprised that no reporter has dug it out. We were thinking then in terms of casualties of hundreds of thousands and not hundreds of millions. It was a much more innocent age but it was warfare and in that sense it was not innocent. All the bombs then had fissionable material and the first one we set off at Trinity near Los Alamos was dirty. It was set off practically at ground level, the fireball touched the ground and in fact a great deal of radioactive contamination was spread, by the standard of those days. The government had a lot of trouble with a herd of cattle whose hair turned white as a result. It was a very dirty bomb.

The bombs at Hiroshima and Nagasaki on the other hand were clean. They were exploded high in the air and few if any casualties were produced by fallout. Possibly there were a handful on a global scale, but practically all the hundreds of thousands who died, and the others who were maimed from radiation and blast, did not have the benefit of fallout. Nevertheless, I vastly prefer our first dirty bomb to those two clean ones.

When all is said and done about these problems—essentially soluble problems—of describing the practical consequences of scientific progress, there remains the central, perplexing question, to which I keep returning, of bringing an appreciation of the new scientific knowledge to the world. It is a question of high importance; it deserves study.

I do not see, for example, how the scientist can evoke the same understanding and grateful warmth from his fellows as the actor who gives them pleasure and insight, and reveals their own predicament to them, or the musician or dancer or writer or athlete, in whom they see their talents in greater perfection, and often their own limitations and error in larger perspective. The power of the new knowledge itself to excite the intelligent public's mind is very different from the days of Newton when the problems under discussion—the course of the heavenly bodies, the laws of dynamics—were not far from ordinary human experience. People could go to demonstrations to see the new principles in action; they could discuss them in salons and cafés. The ideas were revolutionary but not very hard to understand. It is no wonder that the excitement and change and enrichment of culture in Europe that came about as a result of these discoveries were without parallel.

Today there are sciences like that, which are just starting. During the nineteenth century the theory of evolution certainly played this role. And today, in the psychological sciences there are many fundamental points that anyone can understand if he is willing to take the trouble—science here is just beginning to leave the common experience, and the accumulated tradition has not yet grown very far.

Yet as a whole, the problem is formidable. It is not hopeless—much can and should be done. But I do not believe it can be done by the press alone. Part of the solution lies in education, and, I think, part of it lies with just learning to live with it. Our tradition and culture and community of learning have become reticulated, complicated, and non-hierarchal. They have their own nobility if one brings to them the right attitudes of affection, interest, and indefatigability. The new knowledge is not the kind of thing one can ever finally master; there is no place a man can go to get it all straight. But it has its beauty if one knows how to live with it. And the main thing is to recognize this and not to talk in terms of cultures which are unattainable for us, but to welcome those that are at hand.

Because beyond the need for explanation of the practical, beyond the need for information, there will always be the need for a community of meaning and understanding. To my mind this is a basic and central need. It is a very grave circumstance of our time that the overwhelming part of new knowledge is available only to a few people and does not enrich common understanding. I think, nevertheless, that learned folk do have some sense of this community; and I think this furnishes a clue for others, because it comes in part from the similarities of experience in our professional lives—from recognizing points in common and differences in our separate traditions. We have lived in parallel ways through experience and wonder and have some glimmering of a kind of new-found harmony.

This suggests to me that all of us in our years of learning, and many if not most of us throughout our lives, need some true apprenticeship, some hard and concentrated work, in the specialized traditions. This will make us better able to understand one another but, most important of all, it will clarify for us the extent to which we do not understand one another. It will not be easy. It means a major change in the way we look at the world and in our educational practices. It means that an understanding of the scope, depth, and nature of our ignorance should be among the primary purposes of education. But to me, it seems necessary for the coherence of our culture, and for the very future of any free civilization. A faithful image of this in the public press could do a great deal to help us all get on with it.

CRAZY BUT NOT STUPID

I WANT to turn now to a second subject—disarmament—which may seem irrelevant but, as I hope to show, is not entirely so. Somehow it does not seem quite right of me to discuss a question which I regard as quite central for the future of culture without adding at least a few phrases about the anomalous and terrible situation of the new weapons with which, in their origins, I had quite a close connection.

Perhaps I can best start with a story. It seems that a man was driving into an American city to keep an appointment and one of his back wheels came off in front of an insane asylum. One of the inmates stared out of the window at him and the man said to him in desperation, "Look, the bolts are missing from one of my wheels—I've got an important engagement and everything depends on my making it." The man in the asylum said, "Well you've got four wheels, take a bolt from each of the other three and your problem is solved." The traveler looked up and said, "Say, you aren't so crazy." And the inmate replied, "Sure I'm crazy, but I'm not stupid." That may be a good parable for where we stand with our weapons.

I fully respect those who take the cheerful view that matters might be much worse. It would certainly be worse if all Europe were in Communist hands; it would be worse if a third world war had broken out and ravaged our lives and our culture. But the situation is still terribly dangerous. When we come on testimony before Congressional committees that our operations as now planned would call for 300 million deaths, and so on, we are not, I believe, hearing overstatements or misstatements.

Furthermore, it is my impression that those who are in a position to know expect that, for a time at least, technical developments may tend to create a situation much more trigger-happy and much less subject to the enormous control these weapons call for—the control which should perhaps be the first expression of that change in the behavior of states and governments for which we are surely destined if we are to survive.

Yet there is enough anxiety so that there is more and more talk of disarmament, and the governments—which have agonizing responsibilities for maintaining the power and influence of their states—are at last nibbling gently at the subject.

I would be reluctant to create the impression that I do not believe in disarmament. We all know what indescribable difficulties stand in the way of negotiating it and how Utopian it seems to talk of meaningful, effective, adequate disarmament which would protect the world. But my point is a little different. It is not that disarmament is Utopian but that it really is not Utopian enough. There are two quite simple arguments from the nature of scientific progress which bear on the stability and value of disarmament. They are very general principles and they were very much on our minds when, in 1946, a group of people in this country and abroad tried to work out an idea of what the control of atomic energy would mean.

The first point, which I mentioned earlier, is that new discoveries are made with such enormous and unpredictable rapidity that you cannot possibly devise an instrument of disarmament which is to hold good twenty or thirty years from now unless you forbid inquiry and discovery—and you probably could not legislate that even if you wanted to.

The second point is that the acquisition of knowledge is, for practical purposes, and barring global catastrophe, an irreversible thing. If ever the nations do start to fly at each other's throats they will be quite capable of doing again whatever they once learned to do.

AN OPEN WORLD

THESE two propositions meant to us then, and mean to me now, that the world has to be an open world in which, practically speaking, secrets are illegal. They mean that some of the great power and responsibility which habitually and traditionally rest with the nation-states must rest in less national hands which are better able to use it. They mean that ours must be a united world, as it has never been before.

Some part of this redistribution of power can be accomplished through international organizations, and the experience of OEEC and EURATOM and NATO give very great hope for developing into valuable trans-national institutions. NATO, in particular, may have its greatest historic destiny in this hope, rather than in its past.

But, even more than a growing role for the international organizations, these propositions signify to me the greater development of something which pervades the whole of natural science, and most of learning, and which is beginning even to touch our colleagues behind the Iron Curtain. I refer to the fraternal communities of men embarked on specialized work: those who know how to extirpate malaria; those who seek to understand the radio signals coming to us from remote parts of the Universe; those who recreate the early history of man, his art, and his learning. Their knowledge and know-how bind them together as possessors of true community, complementary to the local geographic communities, complementary to the communities of state and civic tradition; they are the warp of community, as the nations are the woof.

These communities of the mind are the human counterpart and the basis of the international institutions that the future must hold in store and on them rests, it seems to me, the hope that we will survive this unprecedented period in the history of man.

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